Towards Passive Explosion Prevention*

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NFPA 69 Standard on Explosion Prevention Systems (1997 Edition) includes only means for active deflagration suppression. Considering that such means are not always practical or reliable, there is also a clear need to include passive means for suppression or eliminating the explosion potential altogether. Passive explosion protection is illustrated with a packing material consisting of specially designed expanded metal network which occupies only 1 to 2 % of the container or vessel volume. The technical basis for its excellent passive explosion suppression capability is discussed and illustrated to be consistent with experimental data.

Various means for preventing deflagration incidents including oxidant and combustible concentration reductions, active deflagration suppression, deflagration pressure containment, spark detection and extinguishing systems, and isolation methods, are detailed in NFPA 69 Standard on Explosion Prevention Systems, 1997 Edition. However, internal vapor phase deflagration incidents involving flammable mixtures continue to occur on a regular basis which can be related to

- Inerting is not always practical or reliable
- Completely eliminating ignition sources are not practical or possible, given the required minimum ignition energy (~ 0.2 mJ) for most hydrocarbon-air mixtures
- Fast acting flame suppressors are not always practical
- Deflagration venting is not always practical
- Total containment is expensive and in many cases not practical

Therefore, in addition to implementing procedures consistent with the NFPA 69 Standard, the potential for deflagration incidents can be further reduced by considering passive means by using packing material consisting of specially designed expanded metal products such as aluminum alloy foil of low density (30 to 50 kg m^{-3}) and very high surface area per unit volume (~ 1000 m^{-1}) resulting only in volumetric displacement of 1 to 2%. In this paper, the technical basis for their excellent passive explosion suppression capability is discussed and illustrated to be consistent with available experimental data.

Expanded Metal Characteristics

The metal mesh is generally available in two different forms (see Figure 1)

- Spherically shaped bodies suitable for packing already existing smaller capacity tanks
- Rolls of different sized structures network for packing new and large capacity tanks

The aluminum alloy is chemically inert with most systems of interest and mechanical stability of the aluminum mesh prevents any collapse. Self-compression due to the mesh's own weight is only about 5% for a stack height of 15 m.

The flame quenching capability of the expanded aluminum network can be illustrated by comparing its characteristic dimension D (m) to the critical flame quenching diameter (D_{crit}). The network dimension is given by

$$D = V / A = \delta / V_{F,M} \cdot 2 \cdot 10^6 \quad (1)$$

where V (m^3) is the volume occupied by the network, A (m^2) is the surface area of the network, δ (μm) is the thickness of the metal foil, and $V_{F,M}$ is the fractional volume

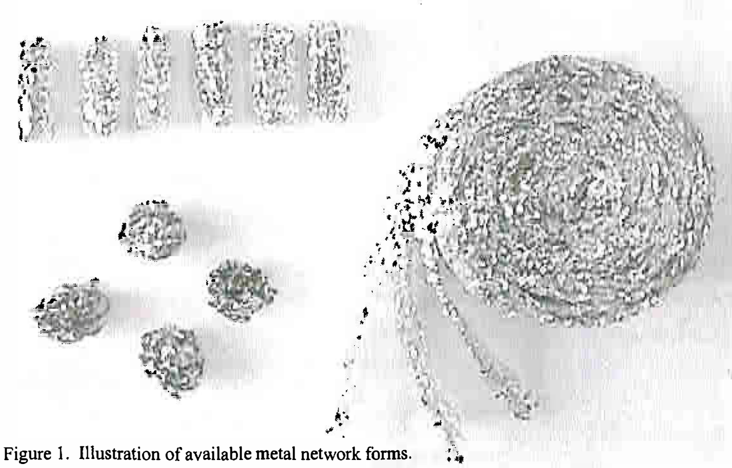

Figure 1. Illustration of available metal network forms.

occupied by the metal mesh. Typical values of D for different values of δ and $V_{F,M}$ are indicated in Table 1, and are of the same order as the critical flame quenching diameter for laminar burns (see Table 2).

Another important characteristic relating to the metal mesh's capability of flame quenching is its heat absorption capability which can be represented in terms of the temperature increase ΔT (K) when subjected to a deflagration burn

$$\Delta T = \Delta H / (V_{F,M}\ \rho\ c) \qquad (2)$$

where ΔH (J/m^3) is the energy release from burning a 1 m^3 stoichiometric fuel-air mixture, ρ (kg m^{-3}) is the theoretical density of the metal foil and c (J kg^{-1} K^{-1}) is the specific heat of the metal foil. Values of temperature increases in the aluminum metal mesh for several stoichiometric fuel-air mixtures are indicated in Table 3. We note from the table, that if the energy absorption by the metal mesh is sufficiently rapid, i.e., approaching equilibrium conditions, the pressure increase due to the burn of a stoichiometric fuel-air mixture (such as a 4 vol.% propane-air mixture) at room temperature (~ 300 K), would only be about (400/300 - 1) = 1/3 bar compared to 8.5 bar in the absence of the metal mesh. Relevant data and further analytical considerations are discussed below that further confirm the excellent suppression capability of the metal mesh.

Experiments and Theoretical Evaluations

While extensive visual demonstrations have been performed with containers and vessels filled with expanded metal networks that illustrate their quenching capability when subjected to fire conditions,* interpretation of the well instrumented tests performed by Ciba-Geigy AG, Switzerland (Bartknecht, 1993), is provided below to illustrate the technical basis for their excellent deflagration suppression properties. Using the standard 20 ℓ sphere apparatus for assessing explosivity, deflagration tests were conducted at room temperature and normal pressure over the entire explosion range of propane in air (volume range 2% - 9.5%) and various fill fractions of the aluminum metal network (δ = 80 µm and density of 40 kg m^{-3}). A continuous spark igniting energy of 10 J was used in the test program. The test results are summarized in Table 4, clearly illustrating the suppression capability of the aluminum network, represented in terms of the aluminum network area, A (m^2).

In order to discuss the data from an analytical point of view, the data in Table 4 is translated from network surface area A, to corresponding vessel fill fractions as follows

$$Vc / V = 1 - \left(\frac{A}{2}\ \frac{\delta}{10^6}\ \frac{\rho_{Al}}{V_T} \right) \Big/ \rho_E \qquad (3)$$

where V_c (m^3) is the vessel volume not occupying the metallic network,

Table 1, Values of the Characteristic Mesh Dimension

δ, µm	$V_{F,M}$ = 0.015 D, m	$V_{F,M}$ = 0.02 D, m
25	8.3×10^{-4}	6.2×10^{-4}
60	2.0×10^{-3}	1.5×10^{-3}
80	2.6×10^{-3}	2.0×10^{-3}

Table 2, Critical Flame Quenching Diameters
(Wilson et al., 1979)

Fuel	D_{crit}, m
Hydrogen	7×10^{-4}
Acetylene	7×10^{-4}
Propane	2.4×10^{-3}
n-Hexan	2.4×10^{-3}

Table 3, Values of ΔT for Several Fuels and $V_{F,M}$

Fuel	ΔH, J m^{-3}	$V_{F,M}$ = 0.015 ΔT, K	$V_{F,M}$ = 0.02 ΔT, K
Hydrogen	3.19×10^{6}	86	64
Propane	3.67×10^{6}	100	75
n-Hexan	3.75×10^{6}	102	76

Table 4, Deflagration Test Results

Safety Network Area A (m^2)	Lower Fuel Concentration (vol.%)	Upper Fuel Concentration (vol.%)	P_{max} (bar)
0.0	2.0	9.5	8.5
0.8	2.25	9.5	6.6
1.2	2.5	9.0	5.4
3.2	2.5	7.5	2.9
5.6	1.5	5.5	0.7

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*EXPLO CONTROL - The Technology to Stop an Explosion videotape available from Explosion Prevention Systems, LLC., 1200 W. Risinger Rd., Fort Worth, TX 76134

V (m^3) is the total vessel volume, A (m^2) is the network area, δ (μm) is the foil thickness, $\rho_{A\ell}$ (kg m^3) is the theoretical density of aluminum alloy, V_T (0.02 m^3) is the test volume, and ρ_E (kg m^{-3}) is the density of the network. The translated data are shown in Figure 2 resulting from the A values listed in Table 4 with $\delta = 80$ μm, $\rho_{A\ell} = 2700$ kg m^{-3}, $\rho_E = 40$ kg m^{-3} and $V_T = 0.02$ m^3. Also included are some data produced by Southwest Research Institute (SWRI, 1988) representing stoichiometric n-Hexane-air mixtures. In the absence of the expanded aluminum network, the 5 Gallon Igloo Gasoline Tank experienced severe failure due to the resulting deflagration event.

From an analytical point of view, the effectiveness of the expanded aluminum network, can be illustrated by starting with the usual assumption invoked in models of closed vessel deflagrations that the fractional pressure rise is proportional to the mass burned

$$P / P_{max} = m_b / m = V_b / V \qquad (4)$$

where

P = final explosion pressure
P_{max} = maximum possible pressure where $m_b = m$
m_b = mass of gas that burns
m = total mass in vessel
V_b = volume of gas that burns
V = total volume of vessel

Assuming that burning can only occur in the volume V_c of the vessel which does not contain the network material the final pressure can be stated as (ignoring the volume of the network material)

$$P / P_{max} = V_c / V \qquad (5)$$

and is illustrated in Figure 2. As indicated in Figure 2, the experimental data discussed above, fall well below Eq. 5 predictions, suggesting that as the burned gas in volume V_c expands into the volume ($V-V_c$) containing the network, is rapidly cooled by the high surface area and relative high heat capacity of the expanded aluminum network. The final pressure can then be approximated by

$$P / P_{max} = (V_c / V)^2 \qquad (6)$$

Predictions from Eq. 6 are in excellent agreement with the experimental data trend as illustrated in Figure 2. This agreement is indicative of rapid equilibration between the expanding burned gases and the network, as well as the flame quenching capability of the network.

Concluding Remarks

The purpose of this paper is to particularly stimulate further use of the passive means provided by expanded metal products in eliminating or suppressing vapor phase deflagration, and encourage inclusion of these means in the next edition of the NFPA 69 Standard. Relevant data and analytical interpretation provided above, clearly justify such consideration.

As such it is of interest to summarize a recent US Air Force Specification for Aircraft Fuel Tanks (USAF, 1994):

- Expanded aluminum mesh; $\delta = 76$ μm and $\rho_E = 40$ kg m^{-3}.
- Combustion pressure increase shall not exceed 15 psi (~ 1 bar) when $V_c = 10$ volume percent and initial pressure = 3 psig (~ 0.2 bar g).
- Test specification: stoichiometric propane/air mixture; ignition source > 0.25 mJ.

The above test requirements are all met by the stoichiometric propane/air data illustrated in Figure 2, and clearly indicate that the aluminum network limits the pressure increase to well below 15 psi for the specified free board value of 10% (see Figure 2).

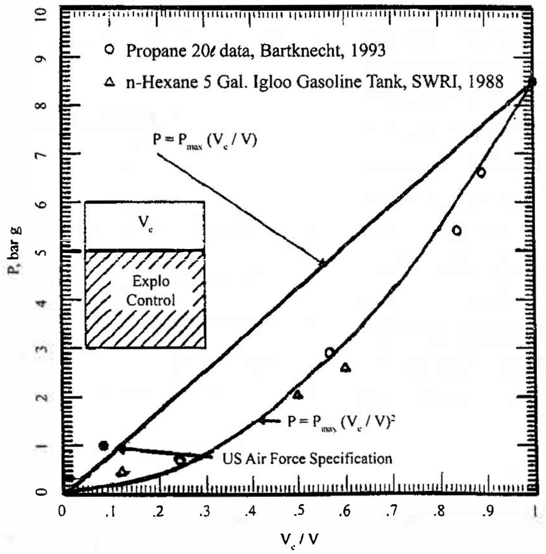

Figure 2. Illustration of experimental explosion data and theoretical predictions.

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